

<b>Project Investigators:</b>	<b><i>Rosemary Capo , Hiroshi Ohmoto , Martin Schoonen , Brian Stewart</i></b>
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### Project Progress

A variety of research was carried out by Ohmoto and his group (Yumiko Watanabe, Research Associate; Katya Bazilevskaya and Tsubasa Otake, graduate students; Denny Walizer, John McGrorey, and David Bevacqua, technicians) to increase our understanding of the evolutionary history of the biosphere, hydrosphere, and atmosphere of early Earth. Our accomplishments during the past year include the following:

1. Geochemical investigations of the Archean Biosphere Drilling Project (ABDP) cores: In summer 2003, under my direction, the ABDP drilled six deep holes in the Pilbara district of Western Australia to recover modern-weathering-free sedimentary and igneous rocks of 3.5–2.7 Ga in ages. In the first drill core, which intersected a 3.46 Ga succession of jasper-chert-pillow basalt, we discovered abundant hematite ( $\text{Fe}^{3+}$ -oxide) crystals. Results from microscopic observations and chemical mapping of these samples using a Horiba X-ray microscope strongly suggest that the hematite crystals formed as a result of mixing of  $\text{Fe}^{2+}$ -rich submarine hydrothermal fluids with  $\text{O}_2$ -rich deep ocean water. This discovery is significant because the presence of free  $\text{O}_2$  molecules in deep ocean water is an indication that the atmospheric  $p\text{O}_2$  level was already more than 50% of the present level at 3.46 Ga. We also discovered that shales (both marine and lacustrine) in all six drill cores contained abundant organic carbon and pyrite ( $\text{FeS}_2$ ), indicating that microbes, including probably cyanobacteria, fermenters, methanogens, and sulfate reducers, flourished in the Archean oceans and lakes. We initiated C and S isotope analyses of these shale samples to better understand the nature of the Archean biosphere.
2. Geochemical investigations of banded iron formations (BIFs): Siderite ( $\text{Fe}^{2+}$ -rich carbonate) frequently occurs as huge massive beds in pre-1.8 Ga marine sedimentary rock sequences. From thermodynamic analyses of the formational conditions of siderite and analyses of C & O isotope ratios of more than 300 siderite samples from Australia and Canada, we (Ohmoto, Watanabe & Kumazawa, 2004) recently

published a paper in *Nature* suggesting that the pre-1.8 Ga atmosphere was CO<sub>2</sub>-rich (pCO<sub>2</sub> > 10<sup>-1.4±0.2</sup> atm, i.e., >100 times the present level) and CH<sub>4</sub>-poor (<

3. Geochemical investigations of pre-2.0 Ga paleosols and so-called “detrital pyrite pebbles”: Our analyses of organic carbon and its host-paleosols (2.7 – 2.35 Ga in ages) from South Africa suggest that land surfaces were fully colonized by microbes by 2.7 Ga ago (Watanabe et al., 2004). Rounded “pyrite pebbles” in some pre-2.2 Ga quartz pebble conglomerate beds have been thought by many previous investigators to be detrital pyrite, and cited as important evidence for an anoxic atmosphere because pyrite is not stable under an oxic atmosphere. Chemical mapping of over 100 “pyrite pebbles” using a Horiba XGT, however, has revealed that the “pyrite pebbles” formed by reactions between rounded pebbles of hematite-rich chert (i.e., oxide BIF) and H<sub>2</sub>S-rich fluids long after the sedimentation of the conglomerate beds. Thus, the “detrital pyrite pebbles” are not evidence of an anoxic atmosphere.

### Highlights

- Massive siderite beds indicate that the atmosphere was CO<sub>2</sub> rich and CH<sub>4</sub>-poor before ~1.8 billion years ago: Many researchers wondered why gigantic beds of siderite (Fe<sup>2+</sup>-rich carbonates) are so common in pre-1.8 Ga sedimentary rocks, but absent in younger rocks. In a paper published in the journal *Nature*, Ohmoto et al. (2004) suggests the reason was that the pre-1.8 Ga atmosphere contained more than 100 times the present atmospheric level of CO<sub>2</sub>; this level of CO<sub>2</sub>, without a contribution from CH<sub>4</sub>, would have provided a sufficient greenhouse effect to counter the lower solar flux and maintain the habitable conditions on early Earth.
- The abundance of red jasper, hematitized pillow basalt, and organic carbon in a deep drill core from Australia indicates that the atmosphere-ocean system was fully oxygenated and that microbes flourished in the oceans 3.46 billion years ago.

### Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

### Cross Team Collaborations

Astrobiology Drilling Project: Bruce Runnegar (NAI HQ; UCLA), Ariel Anbar (UW), Roger Buick (UW).